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Pearson et al.

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(45) **Date of Patent: Apr. 5, 2016**

(54) **FLOW METER WITH ACOUSTIC ARRAY**

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§ 371 (c)(1),
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G01F 1/66 (2006.01)

(52) **U.S. Cl.**
CPC ***G01F 1/66*** (2013.01)

(58) **Field of Classification Search**
USPC 73/861.18
See application file for complete search history.

(56) **References Cited**

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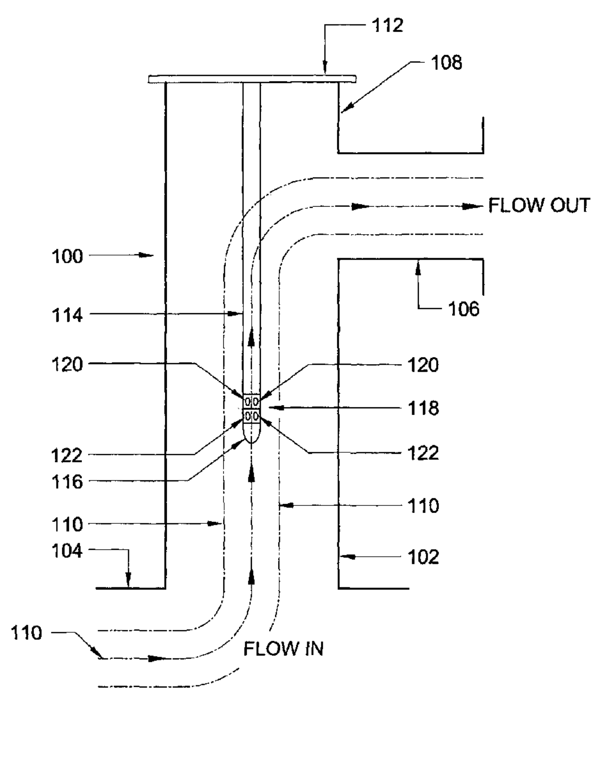
International Application No. PCT/AU2013/000946, International Search Report and Written Opinion mailed Nov. 12, 2013.

Primary Examiner — Jewel V Thompson
(74) *Attorney, Agent, or Firm* — Sheppard, Mullin, Richter & Hampton LLP

(57) **ABSTRACT**

The present invention provides a flow meter for a pipe or open channel. The flow meter has a longitudinal member adapted to be inserted into the pipe or open channel but free of any internal wall of the pipe or open channel. The longitudinal member has a plurality of pairs of acoustic transducers located there around, with each pair of acoustic transducers having a transmitting transducer and a receiving transducer. The transmitting transducer sends an acoustic signal to an internal wall of the pipe or open channel and the receiving transducer receives the reflected acoustic signal.

22 Claims, 27 Drawing Sheets



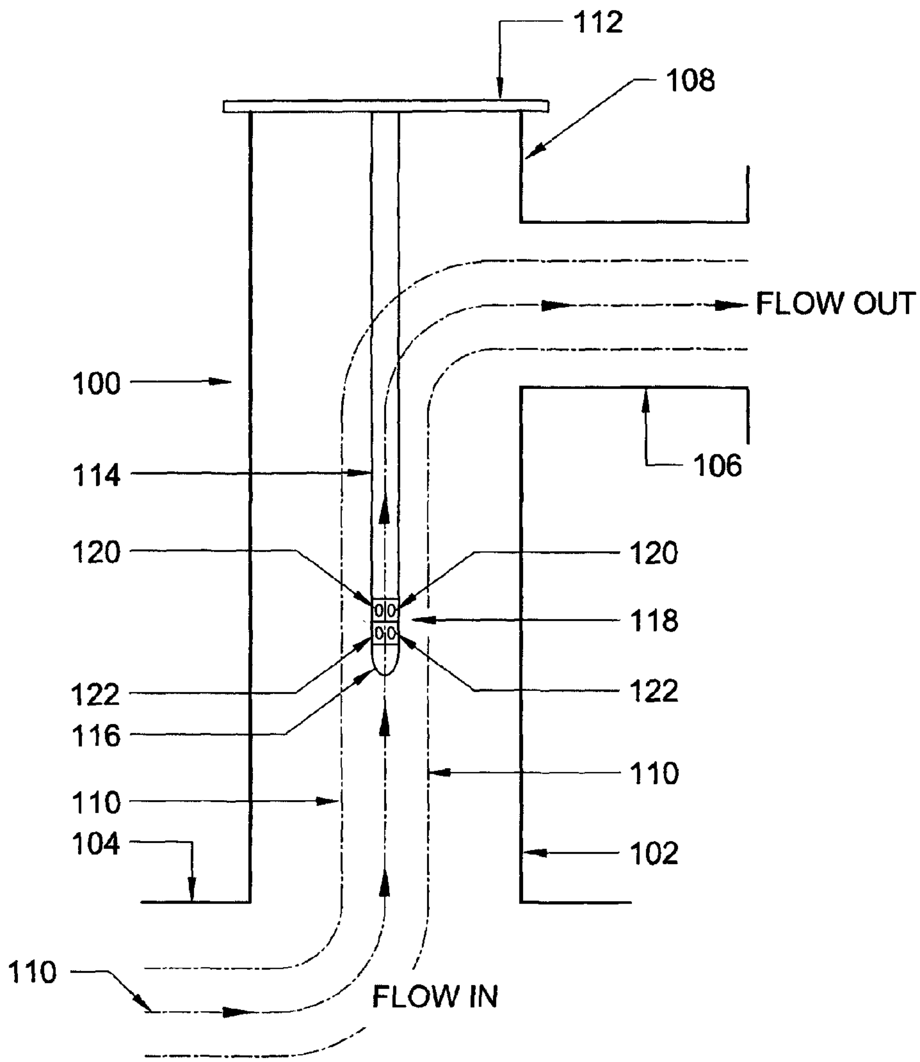

112
108
FLOW OUT
100
114
106
120
120
118
122
122
116
110
110
104
102
110
FLOW IN

FIG. 1

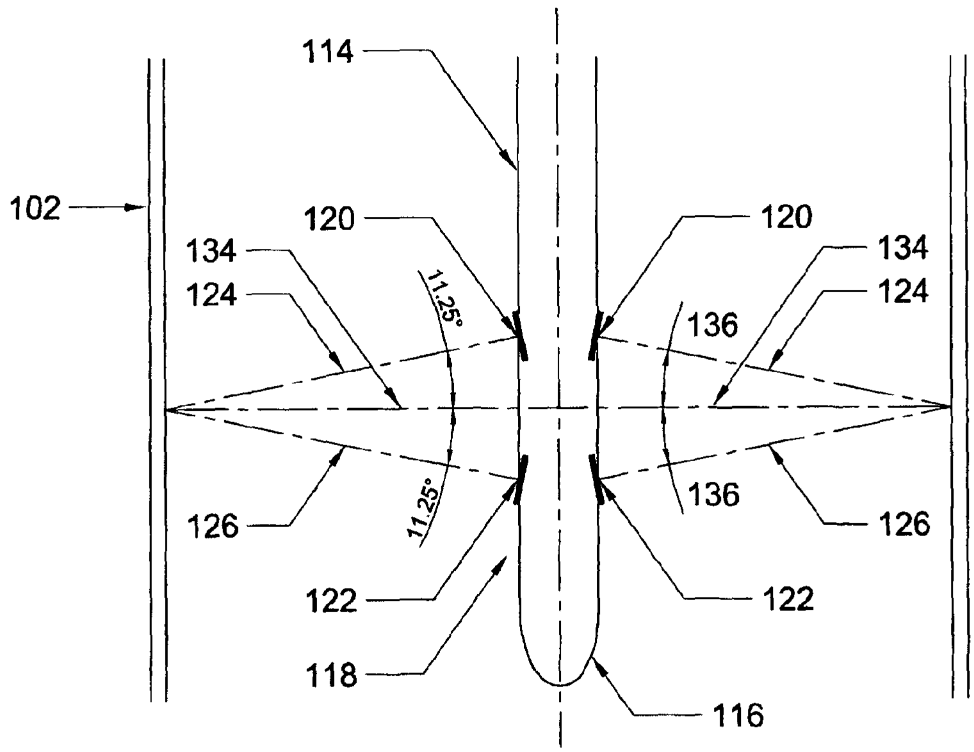

114
102
120
120
134
134
124
124
11.25°
136
136
11.25°
126
126
122
122
118
116

FIG. 2

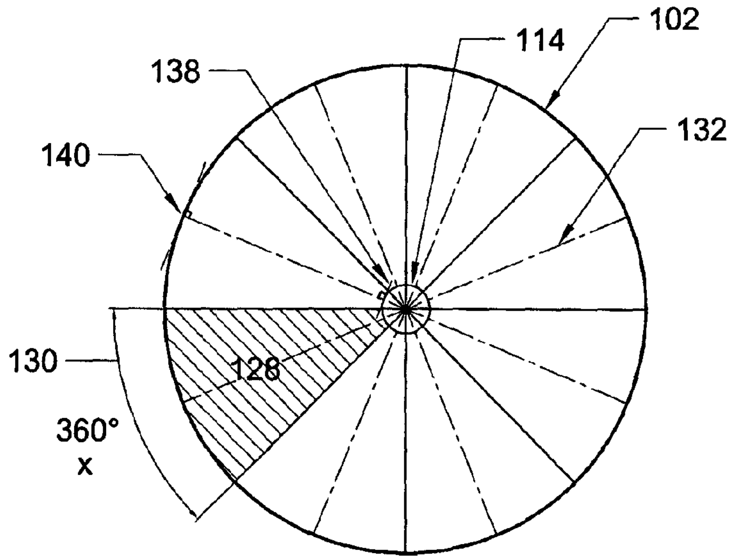

102
114
138
132
140
130
128
360°
x

FIG. 3

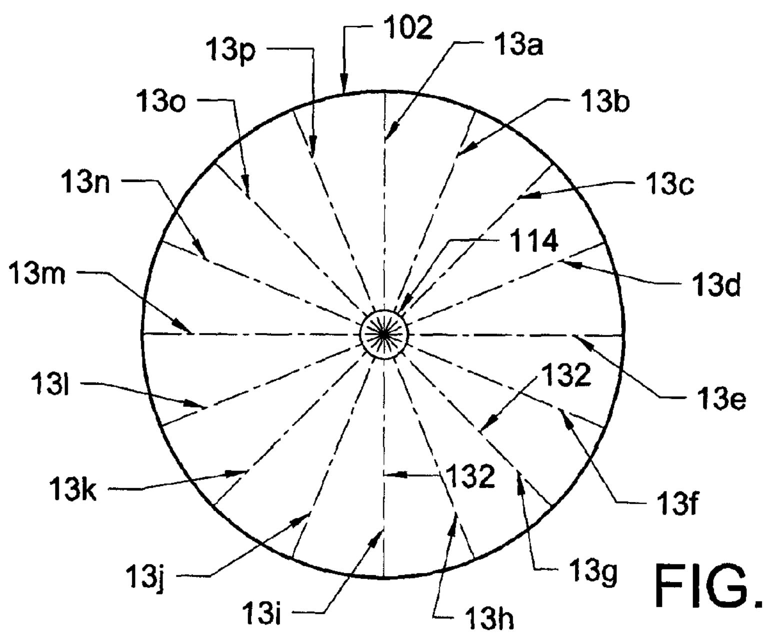
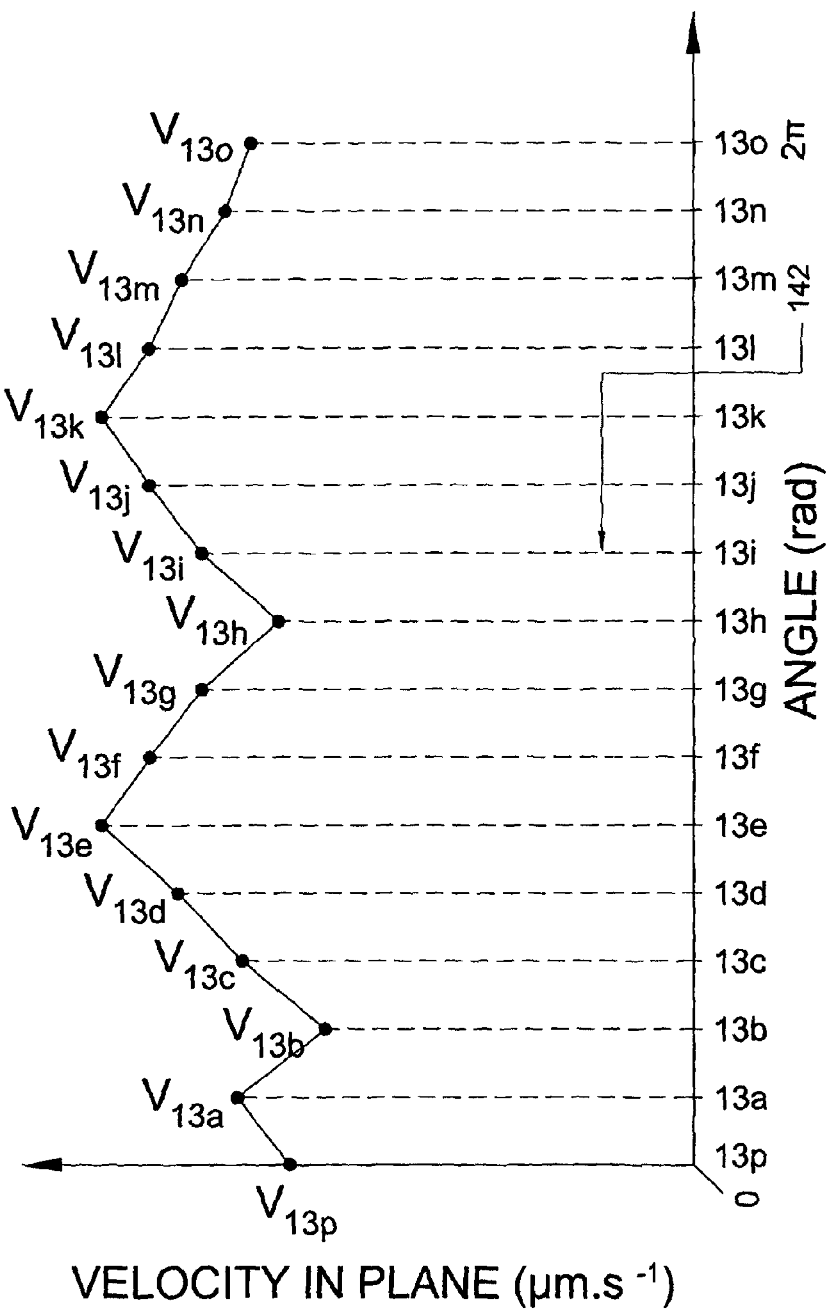

102
13p
13a
13o
13b
13n
13c
114
13m
13d
13e
13l
132
13k
132
13f
13j
13g
13i
13h

FIG. 4


V13o
V13n
V13m
V13l
V13k
V13j
V13i
V13h
V13g
V13f
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V13b
V13a
V13p
13o
2π
13n
13m
142
13l
13k
13j
13i
13h
13g
13f
13e
13d
13c
13b
13a
13p
0
ANGLE (rad)
VELOCITY IN PLANE (µm.s -1)

FIG. 5

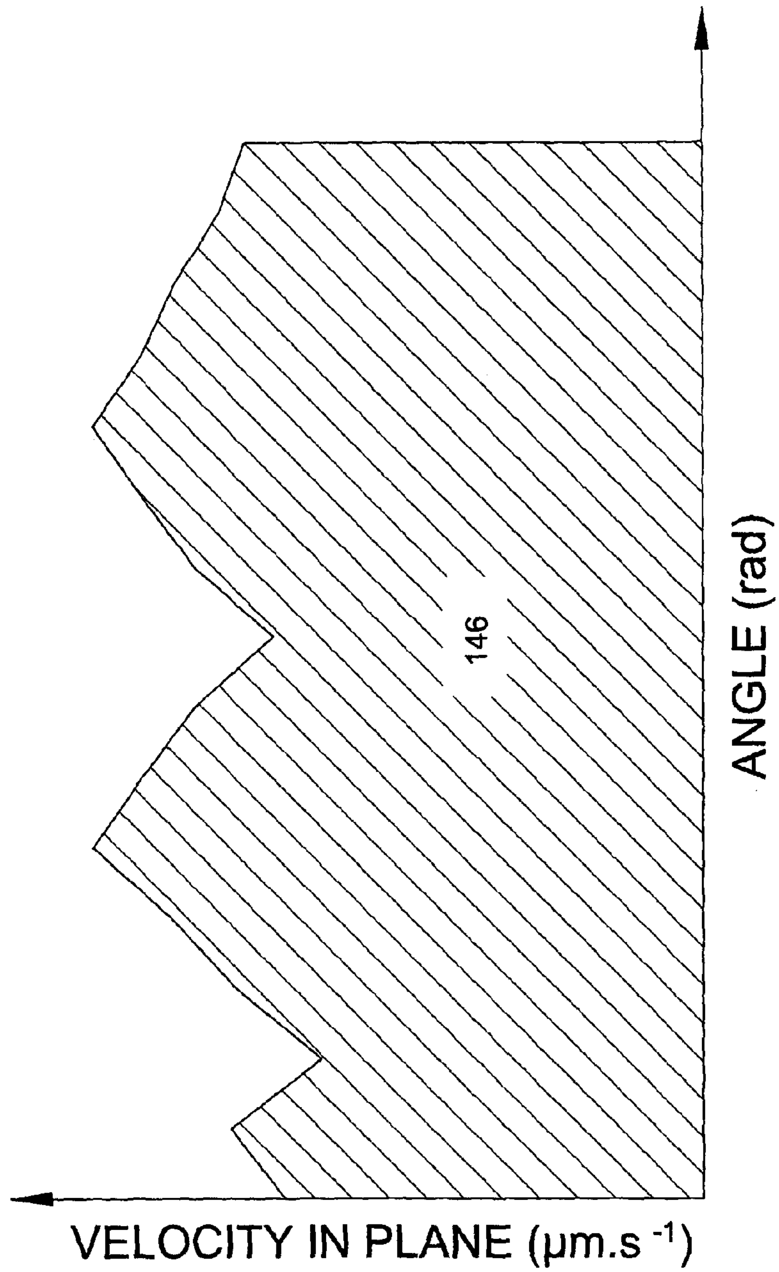

FIG. 6

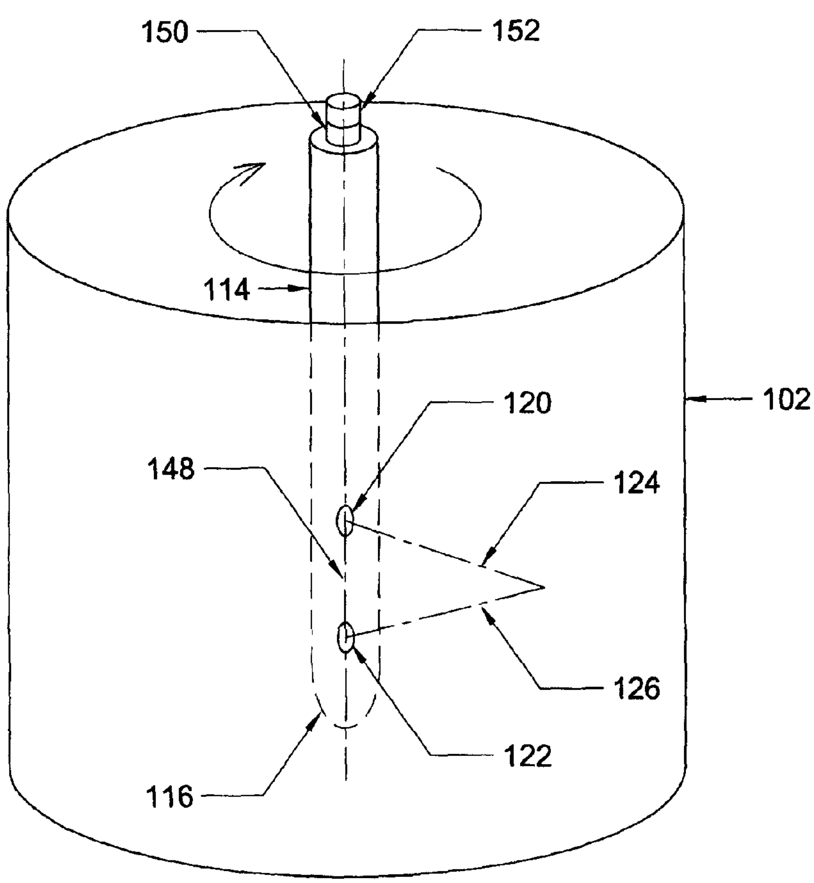

FIG. 7

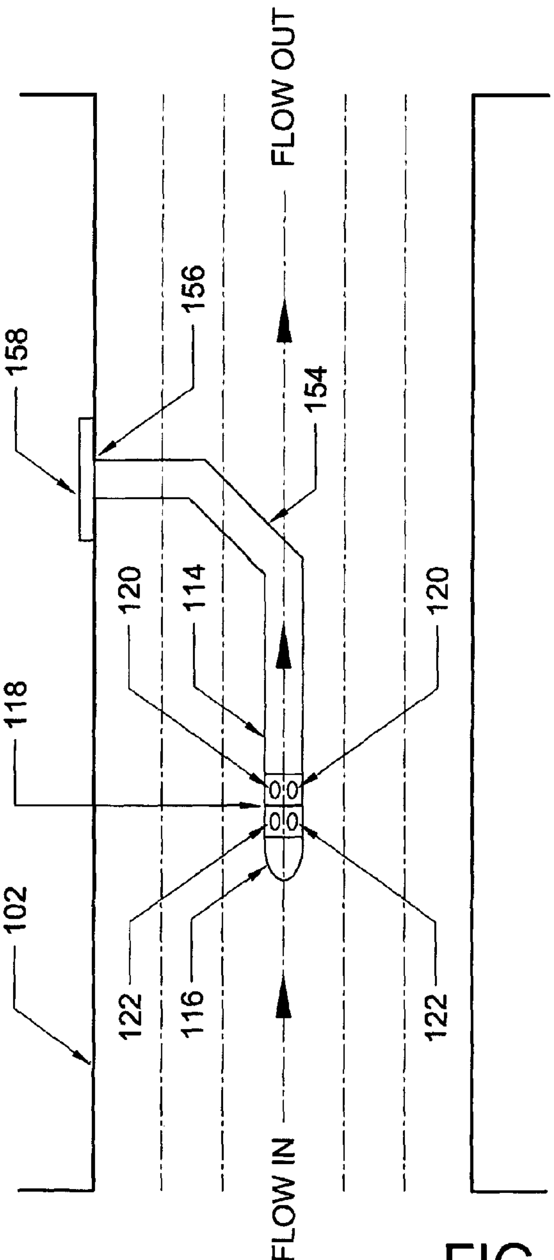

FIG. 8

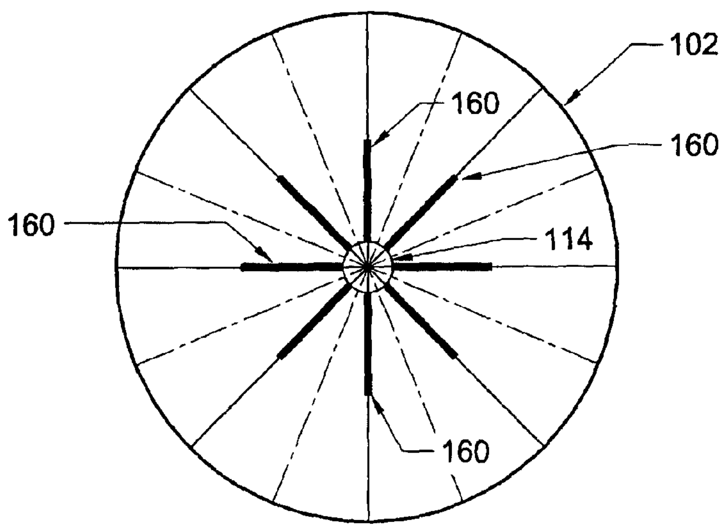

FIG. 9

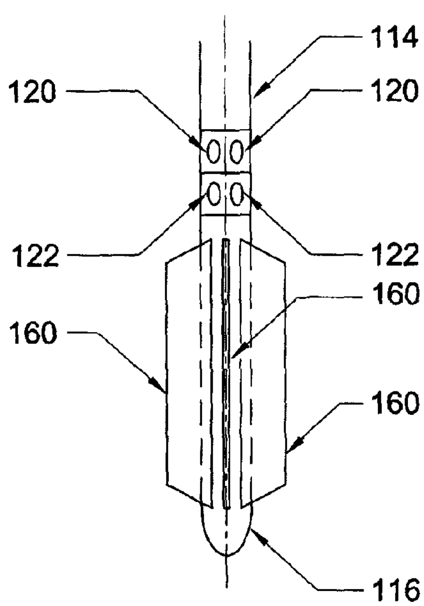

FIG. 10

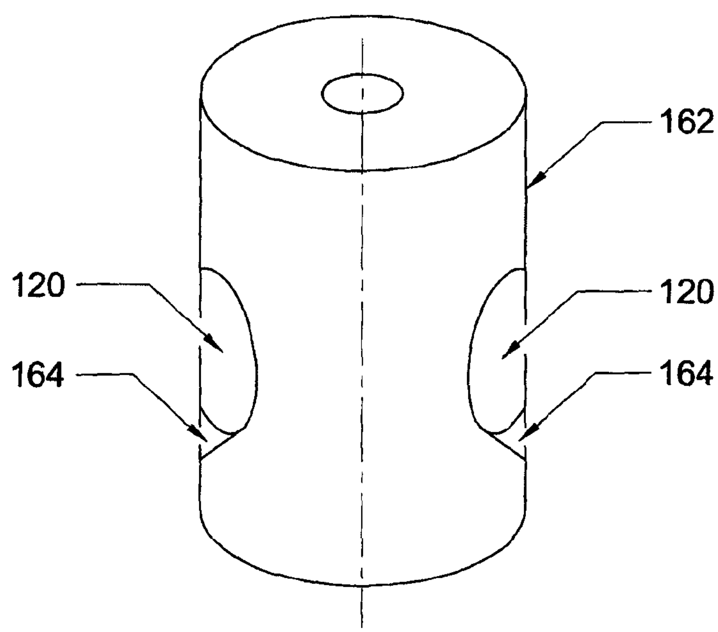

FIG. 11

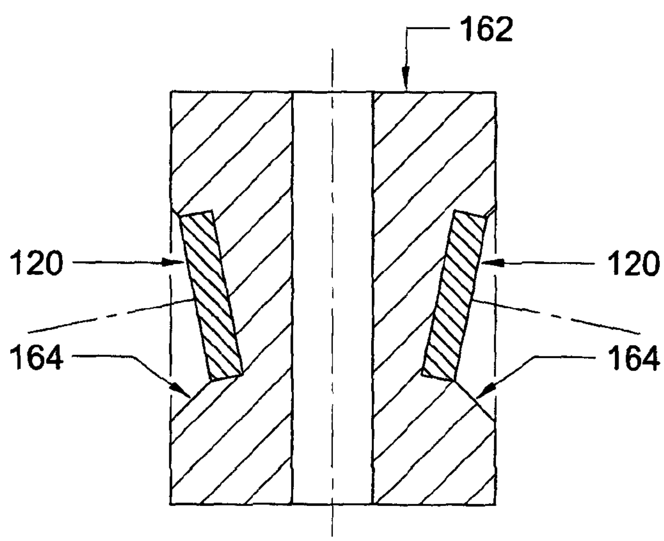

FIG. 12

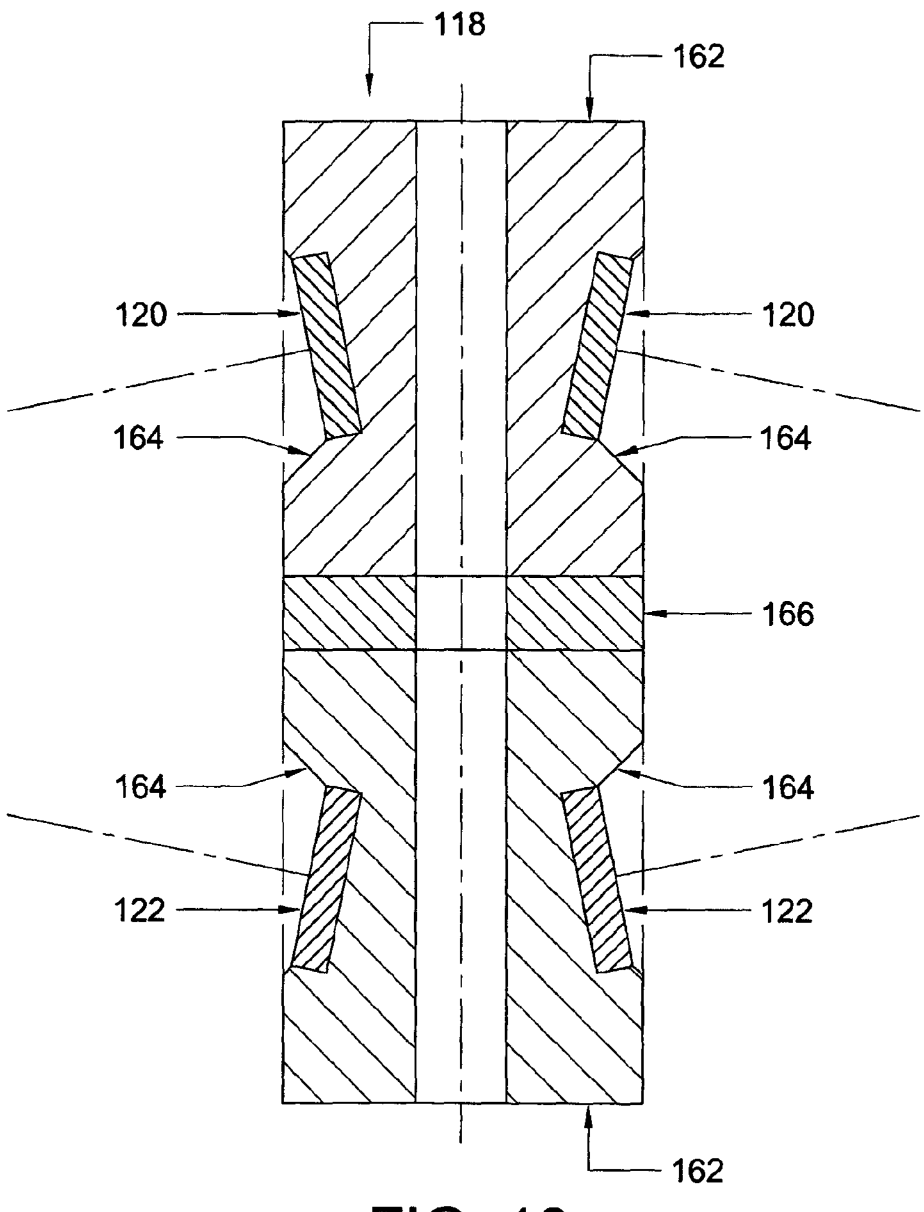

FIG. 13

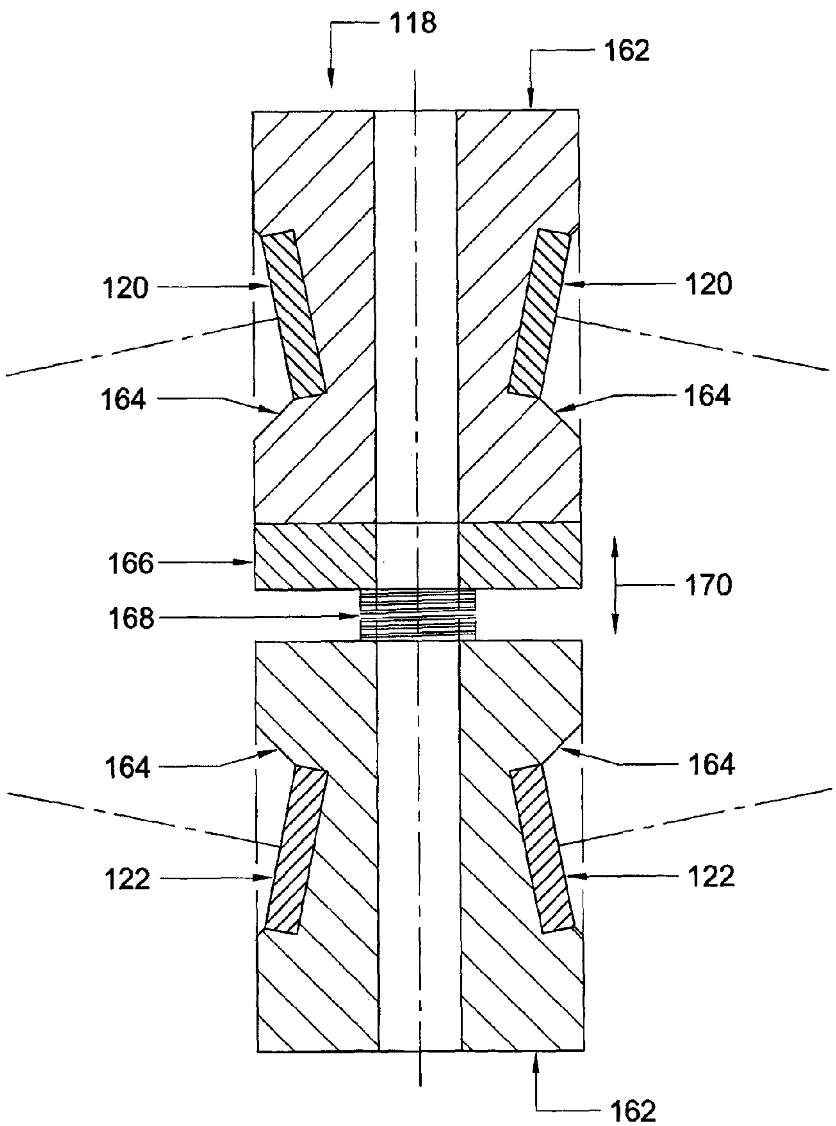

FIG. 14

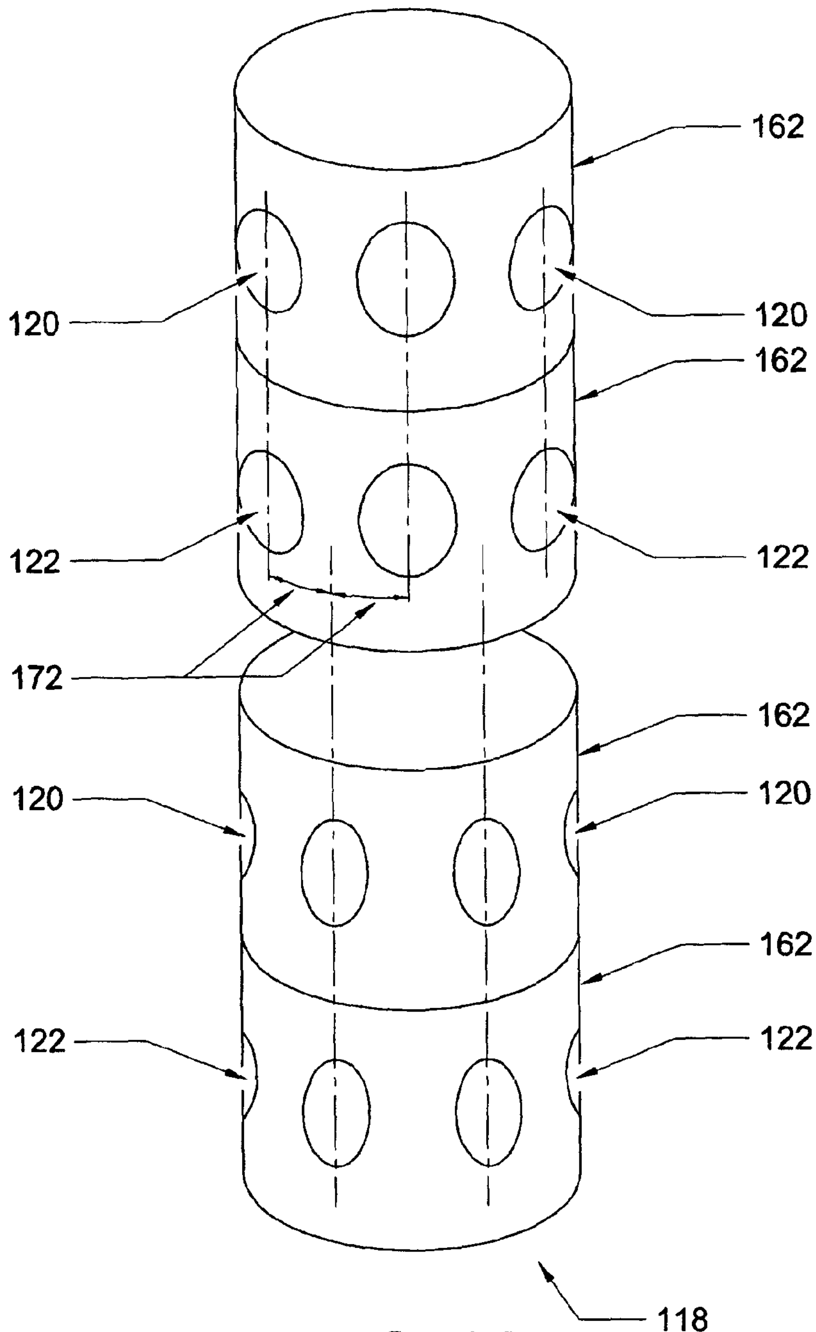

FIG. 15

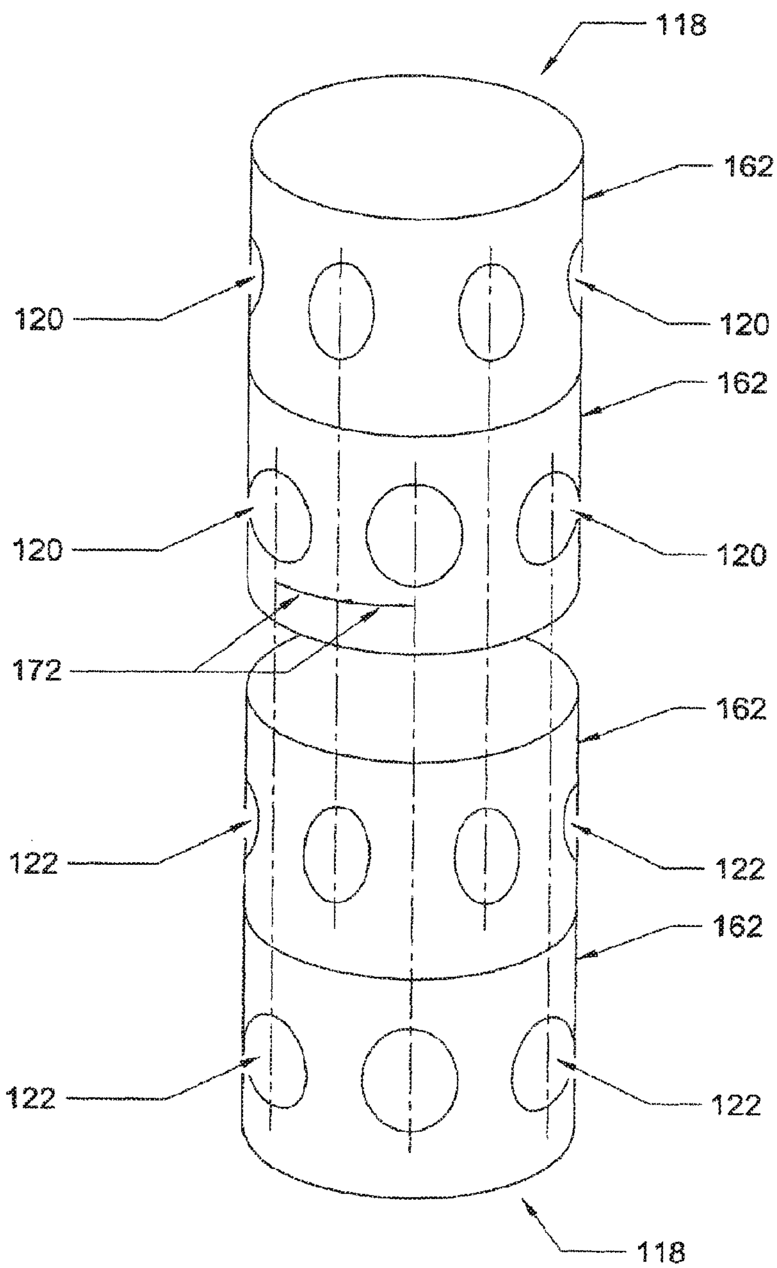

FIG. 15A

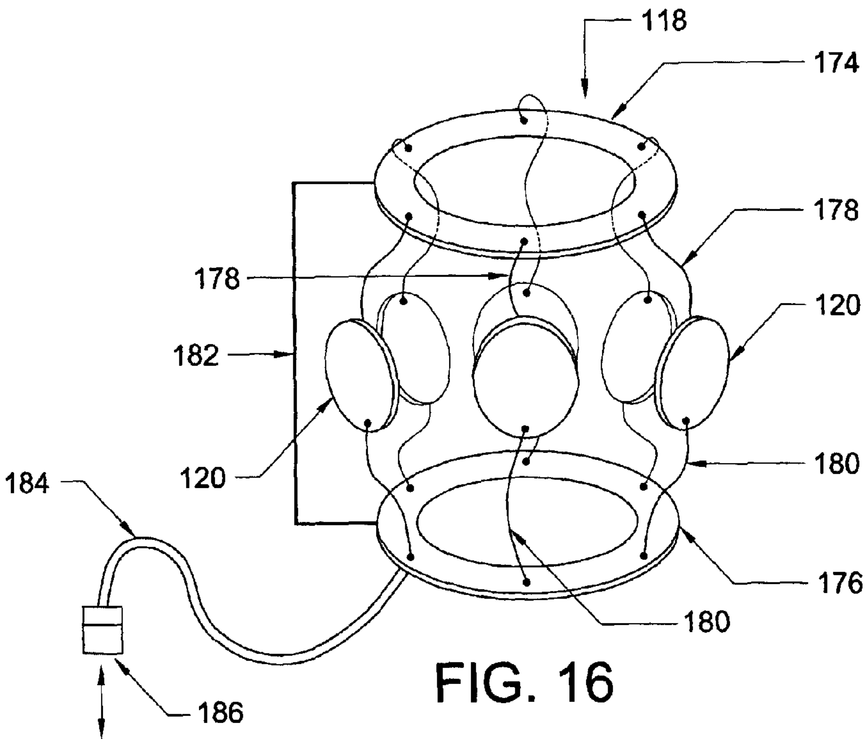
118
174
178
178
120
182
120
184
120
180
176
180
186

FIG. 16

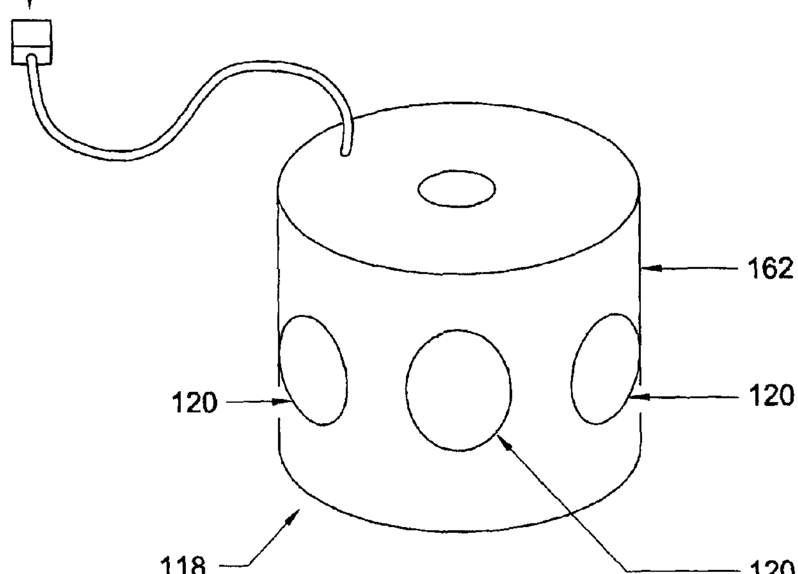
162
120
120
120
118

FIG. 17

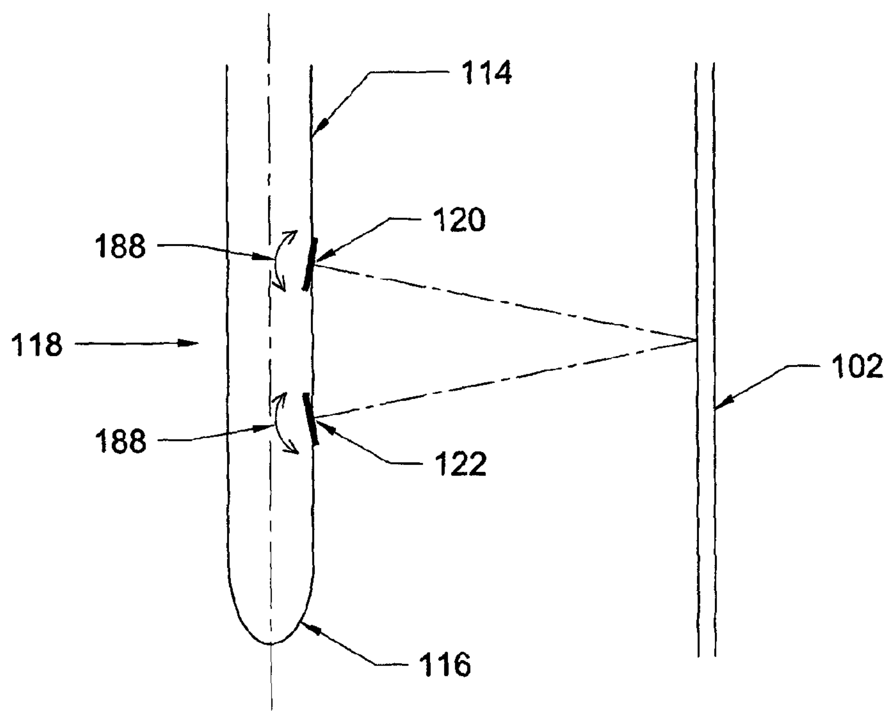

FIG. 18

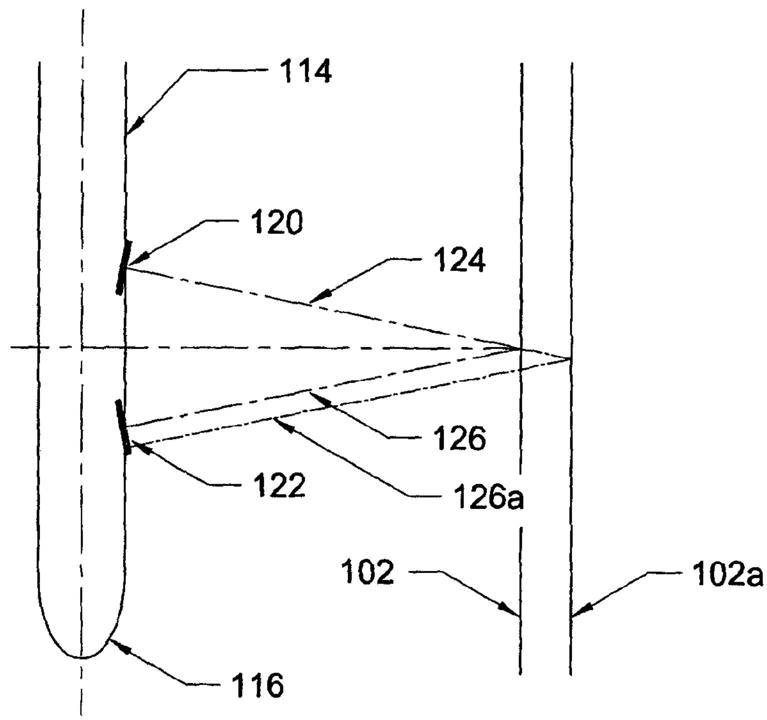

FIG. 19

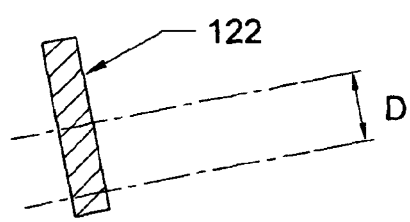

FIG. 20

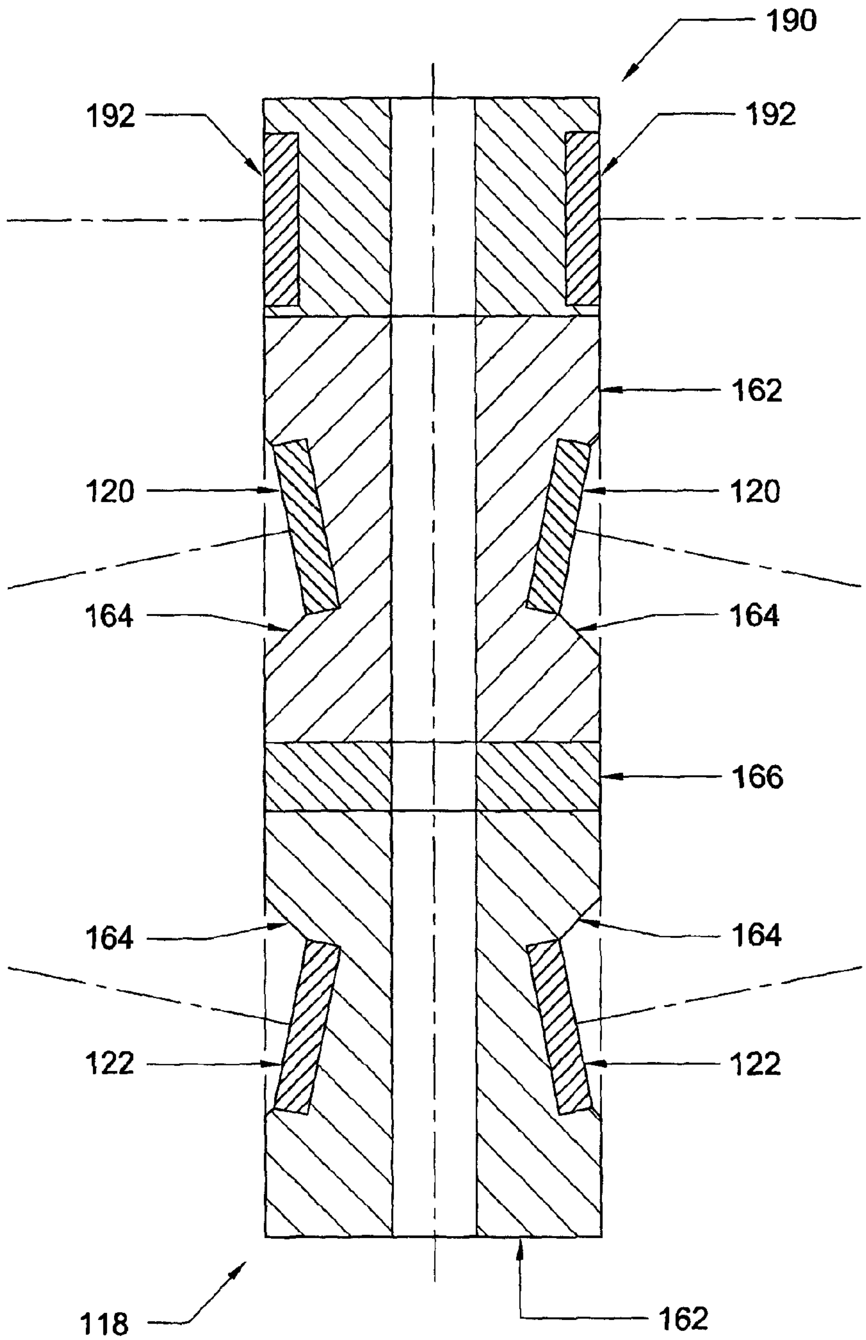

FIG. 21

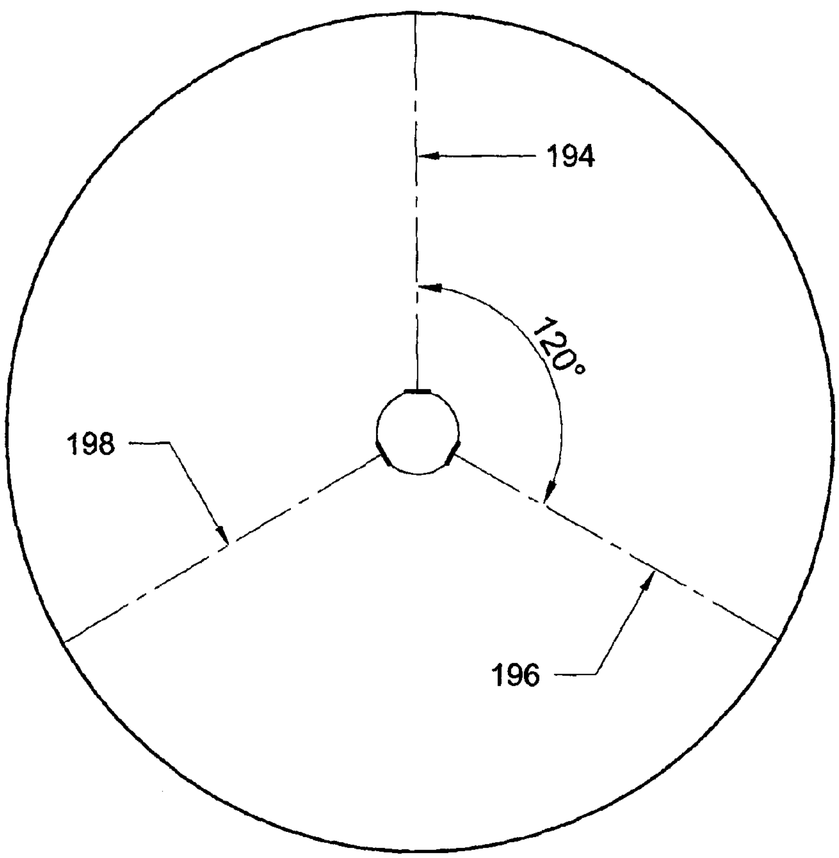

FIG. 22

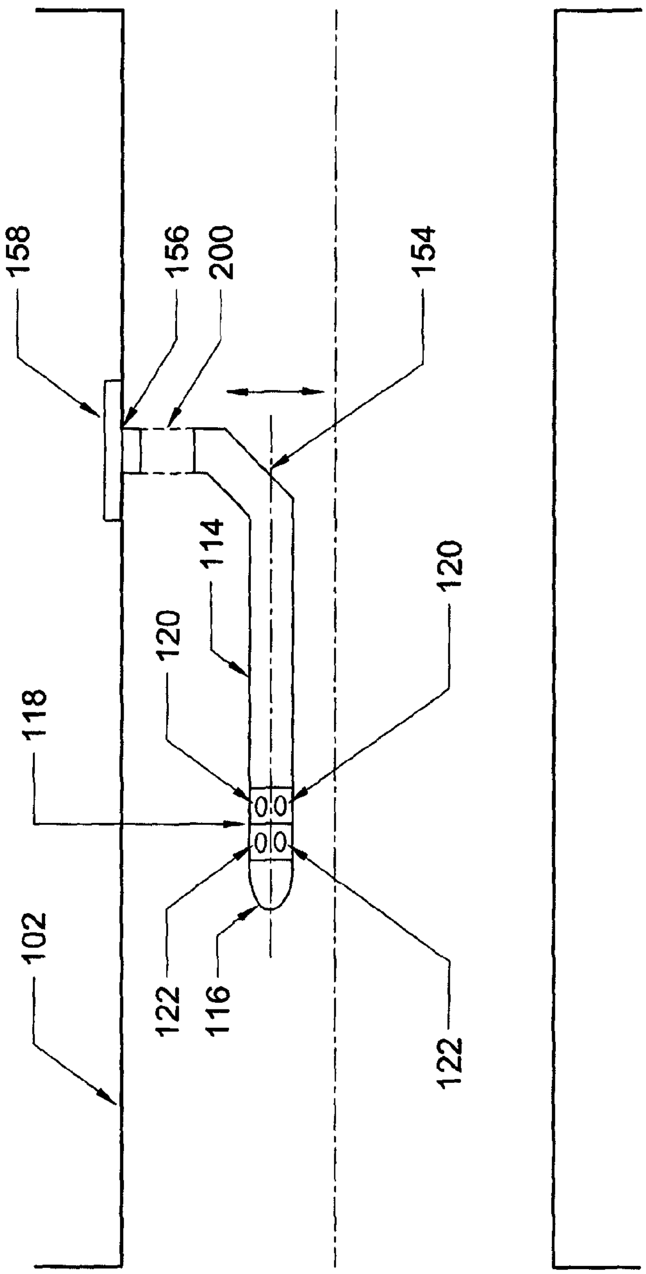

FIG. 23

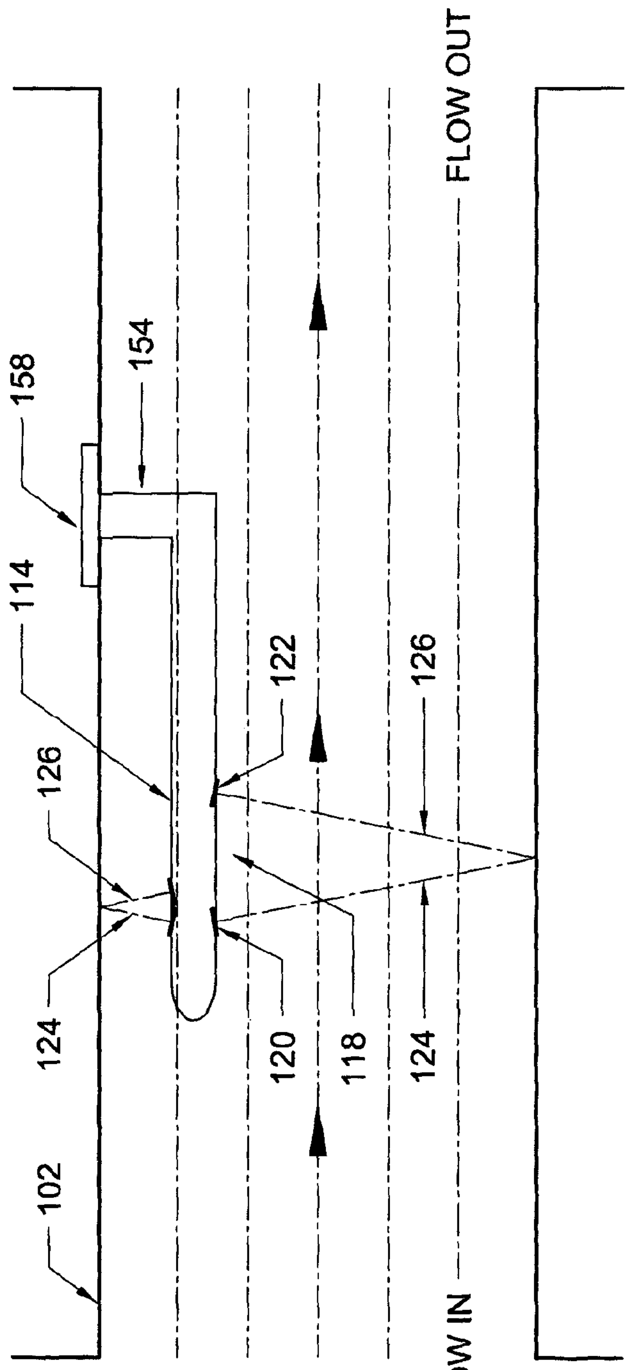

FIG. 24

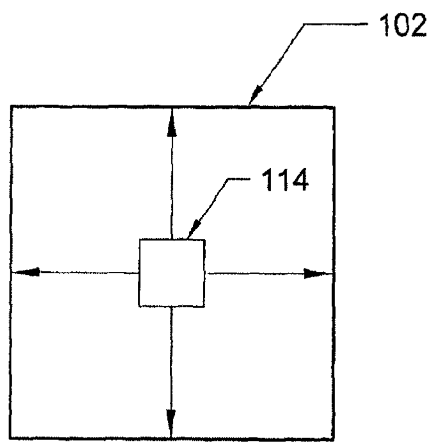

FIG. 25A

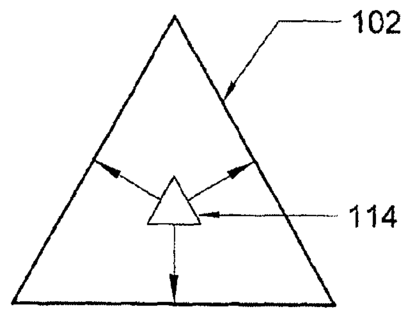

FIG. 25B

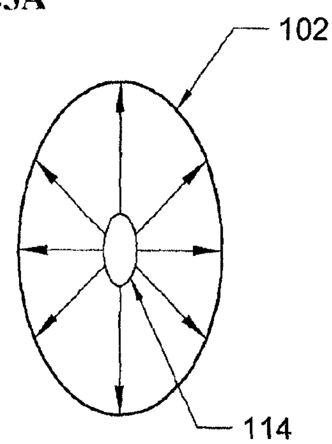

FIG. 25C

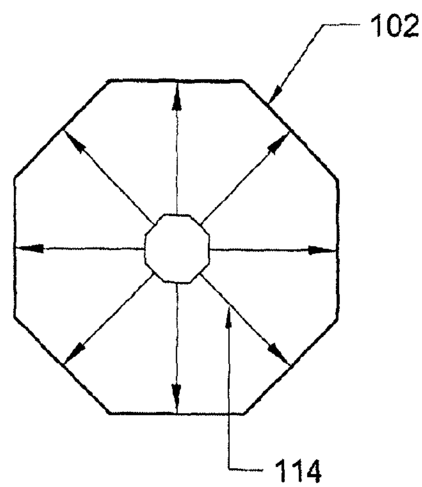

FIG. 25D

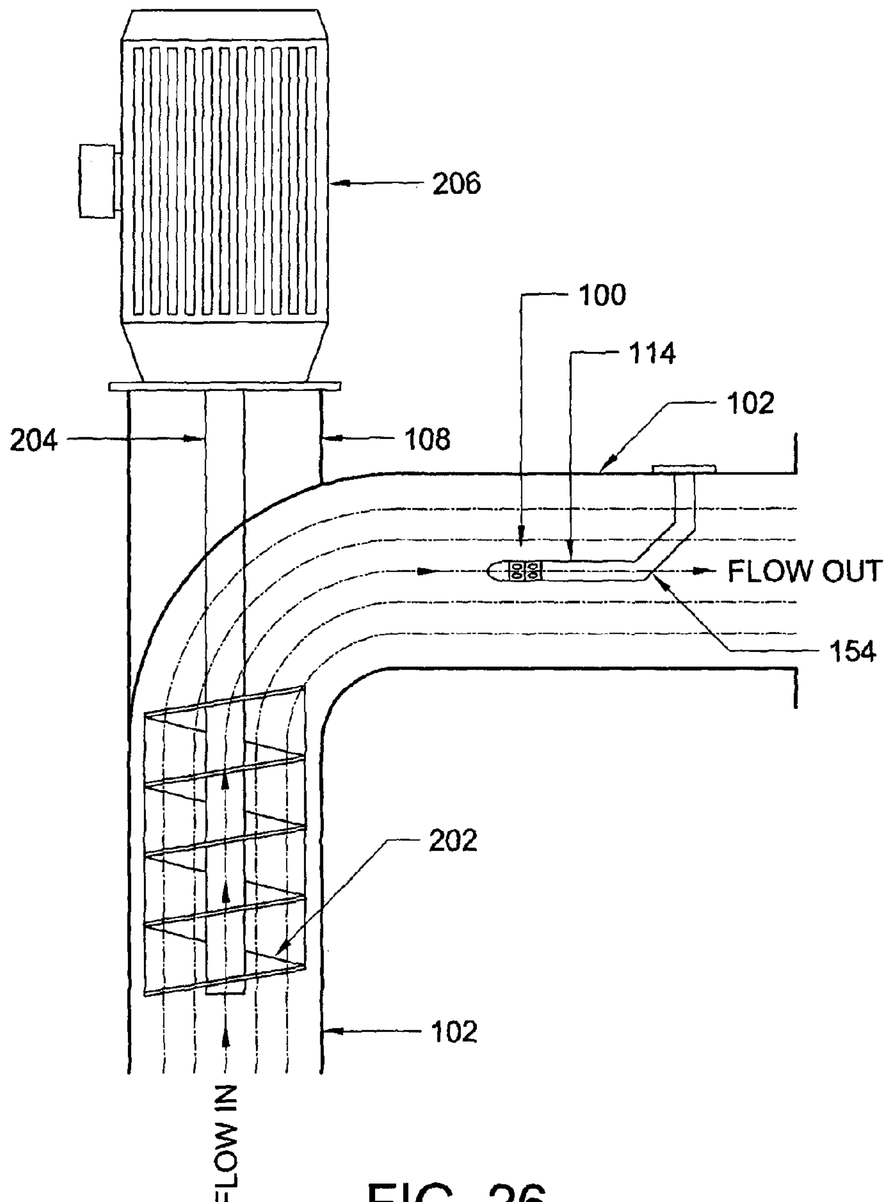

FIG. 26

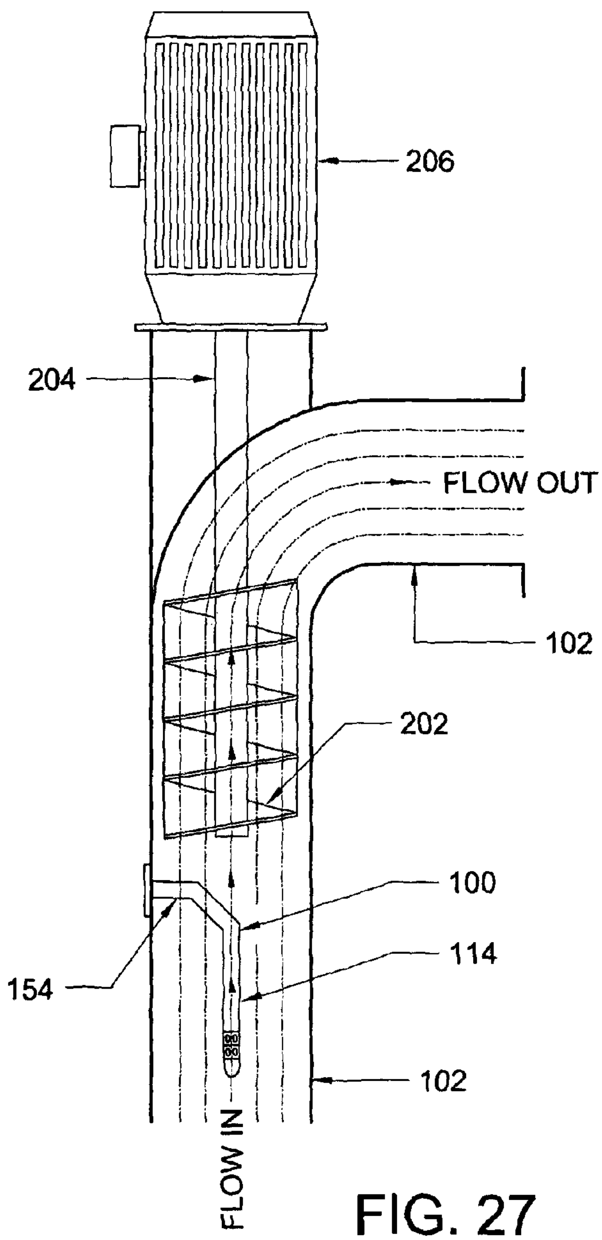

FIG. 27

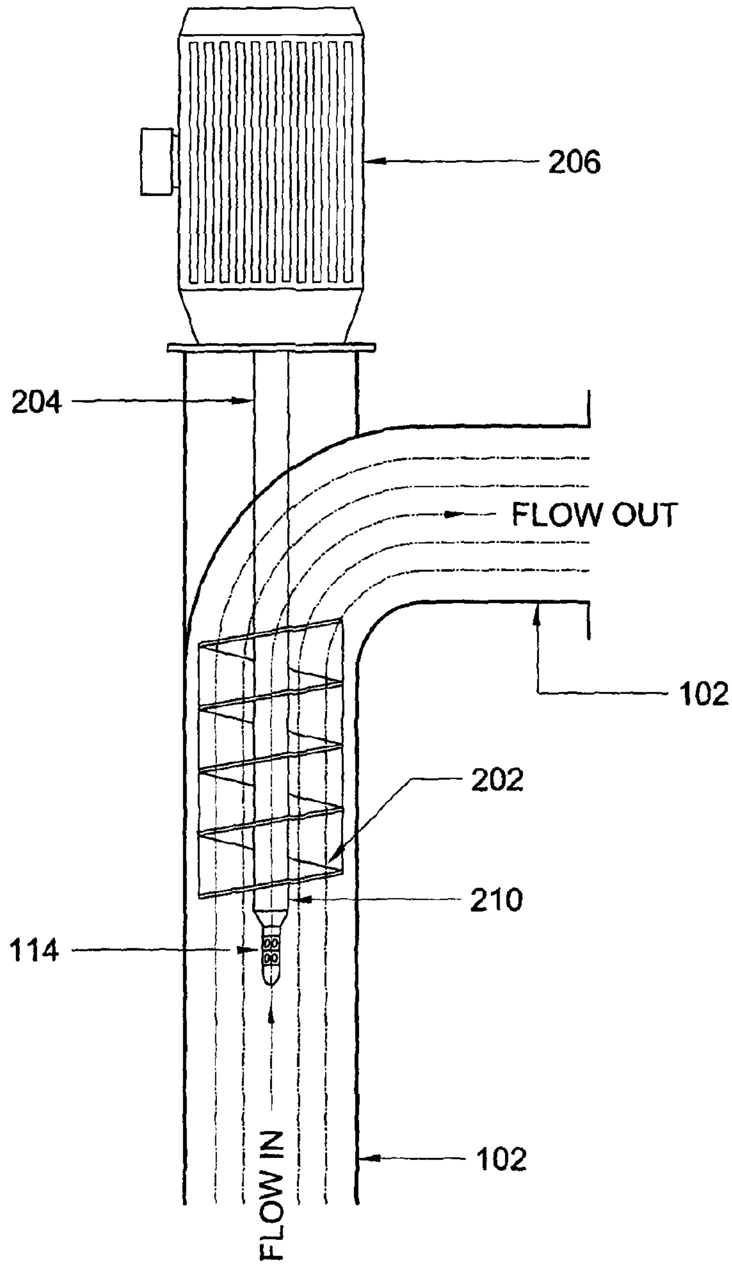

FIG. 28

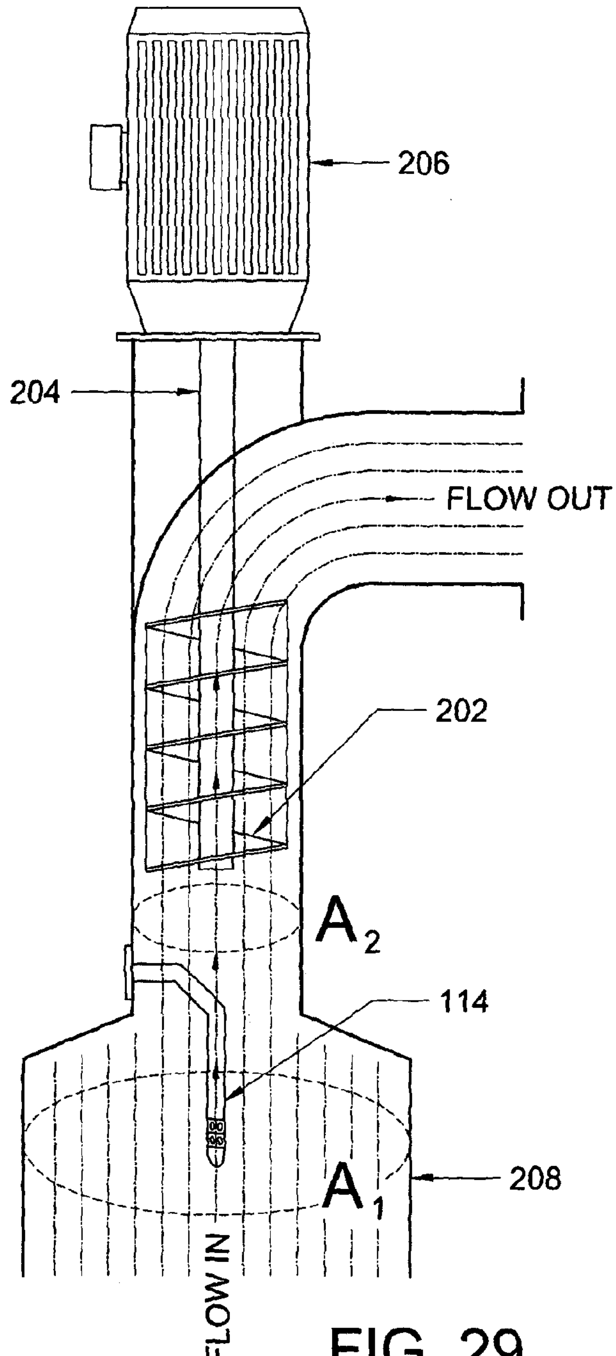

FIG. 29

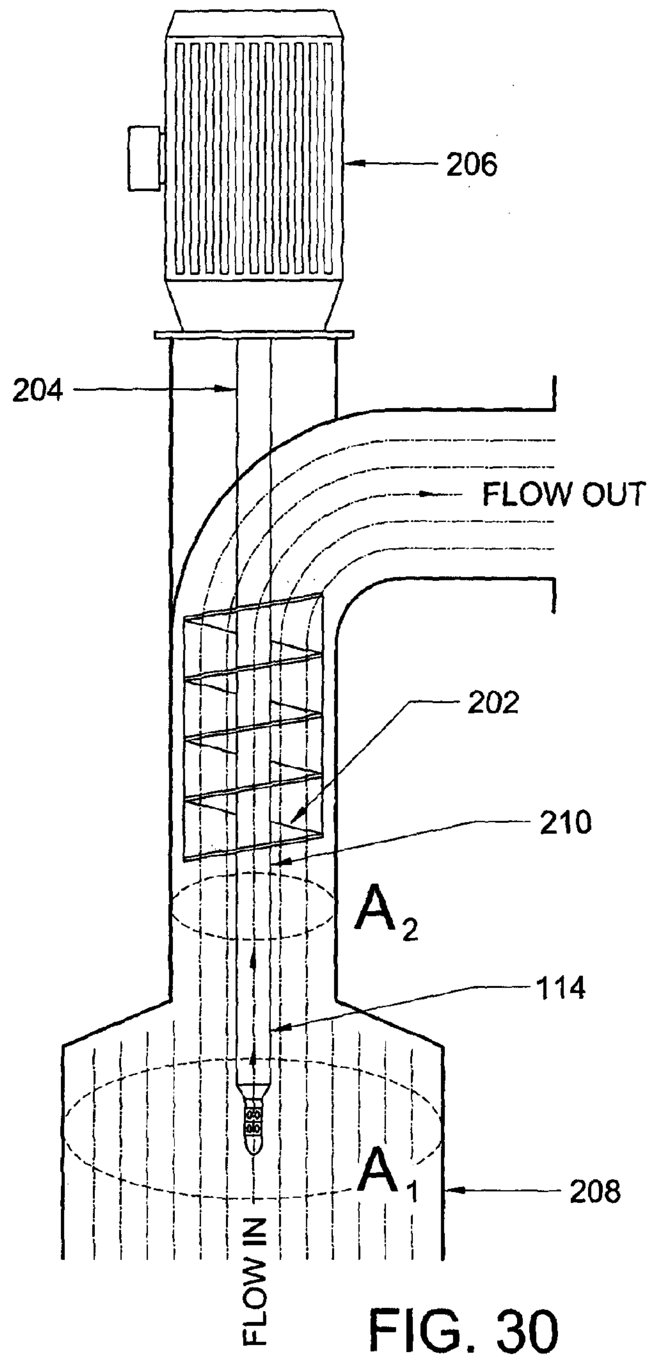

FIG. 30

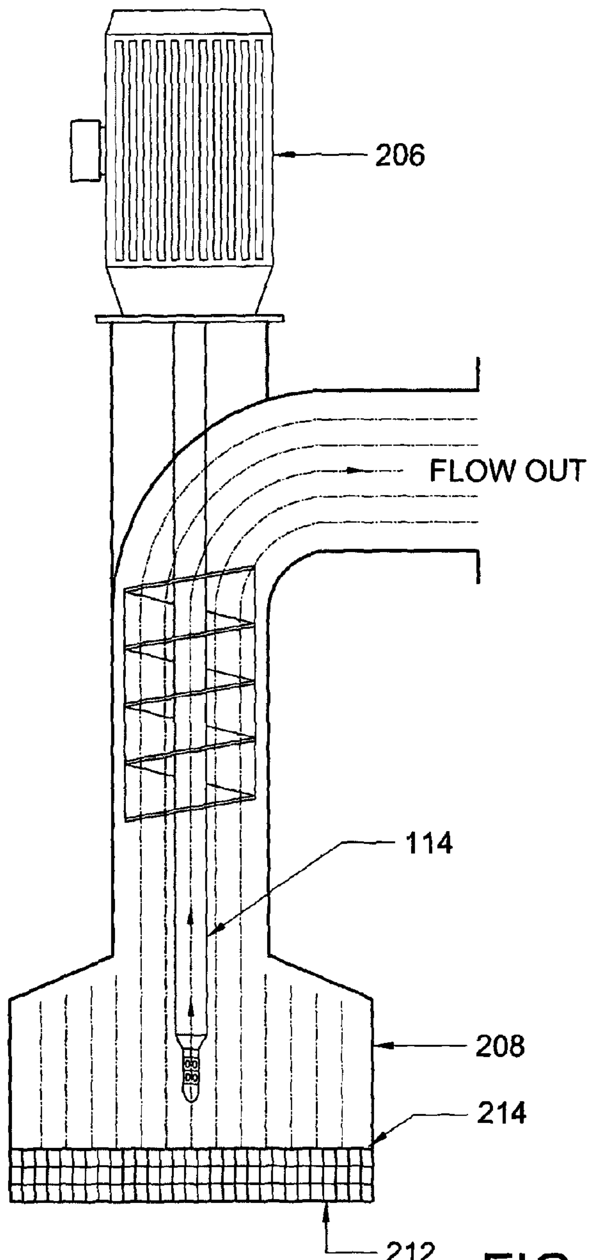

FIG. 31

FLOW METER WITH ACOUSTIC ARRAY

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a national stage application pursuant to 35 U.S.C. §371 of International Application No. PCT/AU2013/000946, filed Aug. 26, 2013, which claims priority to Australian Patent Application No. 2012903697, filed Aug. 28, 2012, the disclosures of which are hereby incorporated by reference herein.

BACKGROUND OF THE INVENTION

The present invention relates to a flow meter for fluids and relates particularly, although not exclusively, to a flow meter for irrigation pipe lines.

PRIOR ART

A popular method of measuring flow rates within pipes is the use of propeller meters. These devices are at least fifty years old and rely on a propeller projecting inside the pipe with its axis located at the centre of, and parallel to, the flow. The spindle of the propeller can be connected by gearing to a measuring meter external to the pipe. The meter can be mechanically based using gearing or can generate magnetic or electric fields which can be associated with an appropriate measuring interface. Propeller meters have been widely used in a standard pipe riser design. These propeller meters are prone to mechanical wear (especially of the spindle bearings), and clogging of the propeller. In culvert pipes the propeller can be easily obstructed by debris and weeds. In addition, it is very difficult to detect a malfunction or unauthorised interference to the meter whilst operating. For accuracy of measurement, propeller meters have limitations on their fitting location within the pipe as they must be located clear of pipe bends.

OBJECTS OF THE INVENTION

An object of the invention is to provide a flow meter that can readily be a drop in replacement for a propeller meter.

A further object of the invention is to provide a flow meter which has no moving parts.

SUMMARY OF THE INVENTION

The present invention provides a flow meter for a pipe or open channel, said flow meter including a longitudinal member adapted to, in use, be inserted into said pipe or open channel but free of any internal wall of said pipe or open channel, said longitudinal member having a plurality of pairs of acoustic transducers located therearound with each pair of acoustic transducers having a transmitting transducer and a receiving transducer, whereby said transmitting transducer sends an acoustic signal to said internal wall of said pipe or open channel and said receiving transducer receives the reflected acoustic signal.

Preferably said longitudinal member has a cylindrical or polygonal shape.

In another preferred embodiment said longitudinal member is secured to an end cap member of a pipe riser fitted to said pipe.

In a practical embodiment said longitudinal member is mounted to a bracket installed through an access port on the side of said pipe. Preferably small angles separate respective

pairs of acoustic transducers to significantly reduce the likelihood of a flow direction change within the measuring area for each pair of acoustic transducers.

The invention may have said longitudinal member mounted on a shaft of an axial screw pump within said pipe. Preferably a plurality of flow straightening vanes is attached to said longitudinal member upstream of said acoustic transducers. The invention may have said acoustic transducers being switchable between receiving and transmitting acoustic signals. A further preferment provides each of said receiving transducers being axially offset from each of said transmitting transducers.

The invention may have a single pair of transmitting and receiving transducers, or it may have a multitude of pairs of transmitting and receiving transducers arranged about said longitudinal member. Preferably said longitudinal member is centrally or eccentrically aligned with said pipe or open channel.

A further aspect of the invention may include each of said transducers being adjustable for correct alignment. Preferably said longitudinal member is rotatable, in use.

Preferably said acoustic transducers are set at the desired angle through appropriate recesses in a body member.

In a further example of the invention an additional acoustic array is included on said longitudinal member to allow for the concentricity of the longitudinal member to be verified.

BRIEF DESCRIPTION OF THE DRAWINGS

The structure and functional features of preferred embodiments of the present invention will become more apparent from the following detailed description when taken in conjunction with the accompanying drawings, in which:—

FIG. **1** is a cross-sectional view of a first embodiment of the invention showing a flow meter located within a pipe having a riser;

FIG. **2** is an enlarged view of a part of the longitudinal member of the flow meter shown in FIG. **1**;

FIG. **3** is a horizontal cross-section of FIG. **2** showing the acoustic paths of the acoustic transducers of the flow meter;

FIG. **4** is a similar view to that of FIG. **3** showing the measurement paths from the acoustic transducers;

FIG. **5** is a graph of the velocity measured in each plane plotted against the angle of that plane for the measurement paths shown in FIG. **4**;

FIG. **6** is the graph of FIG. **5** where the area beneath the line joining the angle-velocity points determines the total velocity passing through the pipe and hence the total volumetric flow rate passing through the pipe;

FIG. **7** is a second embodiment of the invention similar to the embodiment shown in FIG. **1** but having the cylindrical longitudinal member rotated rather than stationary;

FIG. **8** is a cross-sectional view of a third embodiment of the invention showing a flow meter located centrally within a pipe;

FIG. **9** is an end view of a variation of the embodiments shown in FIGS. **1** and **8**, showing flow straightening vanes located on the longitudinal member upstream of the pairs of transmitting and receiving transducers;

FIG. **10** is a side view of the embodiment shown in FIG. **9**;

FIG. **11** is a simplified perspective view of a component forming part of the acoustic array;

FIG. **12** is a cross-sectional view of FIG. **11**;

FIG. **13** is a similar view to that of FIG. **12** with a pair of components shown in FIG. **11** which together form the acoustic array;

FIG. **14** is a similar view to that of FIG. **13** showing an adjustment member between components which is used to configure the flow measurement device to suit the internal diameter of the pipe into which it is inserted;

FIG. **15** is a perspective view showing the use of multiple acoustic arrays to increase the angular resolution of the velocity samples measured by the flow measurement device;

FIG. **15**A is a similar view to that of FIG. **15** where the acoustic arrays are interleaved:

FIG. **16** is a perspective view of the method of formation of the component shown in FIG. **11**;

FIG. **17** is a similar view to that of FIG. **11** showing the coupling of the components together;

FIG. **18** is a similar view to that of FIG. **2** showing a variation of the adjustability of acoustic transducers;

FIG. **19** is a similar view to that of FIG. **18** showing the effects of an off-centre location of acoustic array within the pipe;

FIG. **20** is an enlarged view of the circled area in FIG. **19**;

FIG. **21** is a similar view to that of FIG. **13** showing the use of an additional acoustic array to measure the internal diameter of the pipe the array is inserted into and to verify concentricity with this pipe;

FIG. **22** is a plan view of FIG. **21**;

FIG. **23** is a similar view to that of FIG. **8** showing the installation of the flow meter within a pipe and a means of adjusting the diametric length of the mounting bracket to achieve concentricity with the pipe;

FIG. **24** is a similar view to that of FIG. **8** showing the use of the flow meter mounted eccentrically rather than concentrically;

FIG. **25** shows a selection of non-circular or polygonal pipes which can be included as part of the invention;

FIG. **26** illustrates the use of the flow meter at the discharge end of a pump located in the pipe;

FIG. **27** is a similar view to that of FIG. **26** with the flow meter at the intake end of a pump located in the pipe;

FIG. **28** is a similar view to that of FIG. **26** with the flow meter at the intake end of a pump located on the shaft of the pump;

FIG. **29** is a similar view to that of FIG. **27** with an enlarged diameter intake;

FIG. **30** is a similar view to that of FIG. **28** with an enlarged diameter intake; and

FIG. **31** is a similar view to that of FIG. **30** with a filter cage fitted to the intake.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In order to avoid duplication of description, identical reference numerals will be shown, where applicable, throughout the illustrated embodiments to indicate similar integers.

In FIGS. **1** and **2** there is shown a flow meter **100** incorporated into a riser pipe **102**. Riser pipe **102** is coupled to an inlet pipe **104** at one end and an outlet pipe **106** at the other end. The riser pipe **102** is provided to allow measurement of flow velocity of moving liquid as indicated by arrows **110**. Such a setup is commonly used as previously discussed in relation to the prior art with a propeller meter (not shown) inserted through an access flange stub **108** and set into position with a cap member **112** to which the propeller meter would be fitted. In this embodiment the propeller meter could be interchanged with the flow meter of the present invention as hereinafter discussed.

A smooth cylindrical longitudinal member **114** is concentrically located within pipe **102** and attached to cap member **112**. Member **114** has an aerodynamic nose **116** to reduce turbulence and interference with the flow of liquid through pipe **102**. The aerodynamic nose may be located several diameters upstream of the acoustic transducers to allow the flow streamlines to align parallel to the pipe walls before crossing the acoustic array. A streamlined aerodynamic nose **116** on the upstream end of member **114** will reduce the head loss that the member will contribute in obstructing flow and to reduce the likelihood of debris fouling upon the member. The member **114** may have an aerodynamic profile at both ends such that the member does not unduly create head loss in bidirectional flows. An acoustic array **118** is assembled around the outer periphery of member **114**. Acoustic array **118** has a plurality of acoustic transducers **120**, **122** arranged in vertically offset pairs to provide transmitting and receiving transducers. In practice, each transducer **120**, **122** serves a dual purpose of transmitter and receiver and is controlled by software which is programmed to alternate each transducer between each of these two purposes. FIG. **2** illustrates that the acoustic transducers **120** are angled to provide an incident path **124** and a reflected path **126** by reflection from the internal wall of pipe **102**. Accordingly, the speed of sound within the fluid is determined by summing the two measured flight times of the incident path and reflected path and dividing this by the sum of the known equal path lengths **124** and **126**. The difference in the two measured travel times is directly proportional to the velocity of the fluid passing through the measurement plane defined between the outer diameter of the acoustic array **118** and the internal wall of pipe **102**.

A pair of transmitting and receiving acoustic transducers **120**, **122** could be used but greater accuracy is obtained by using a greater number of pairs of transmitting and receiving acoustic transducers **120**, **122** spaced around member **114**. The use of more than two transducers **120**, **122** provides measurement redundancy, and allows the flow meter to continue measuring accurately even if one or more transducers fail. This reduces maintenance costs by allowing scheduled rather than reactive maintenance. FIGS. **3** and **4** show the angular range of 360 degrees around the circumference of the pipe **102** can be divided into a plurality of sectors **128** each containing an angular span **130** of **360**/x where x is the number of sectors that pipe **102** is hypothetically divided into. A radius **132** is defined passing through the angular mid-point of each sector. Each of the measurement planes **134** of the acoustic array **118** is coincident with each of these radii **132**. At the intersection of the cylindrical periphery of member **114** and the measurement plane **134**, an orthogonal plane **138** is defined which is parallel with the tangent **140** to the internal wall of pipe **102** at its intersection with the measurement plane **134**. This orthogonal plane **138** defines the orientation of an acoustic transducer **120**, **122** located at the radial intersection of the cylindrical periphery of member **114** and the measurement plane **134**. It can be seen that along each of the measurement planes **134** two acoustic transducers **120**, **122** are located either side forming an angle **136** relative to the internal wall of pipe **102**. Sound is transmitted radially outward from transmitting transducer **120** and travels to meet the internal wall of pipe **102** at an angle **136**. In this embodiment the angle **136** is illustrated as 11.25 degrees, however any angle may be used from 0.1 degrees through to 89.9 degrees as is practical. The transmitted sound reflects off the internal wall of pipe **102** at an angle of reflection equal to the angle of incidence **136** and travels back to the receiving transducer **122**. The flight time of this transmitted sound is measured by timing electronics (not shown) as previously described in International Patent Application No. PCT/AU2010/001052 and in the ISO Standard 6416:2004(E) Hydrometry—Measurement of discharge by the ultrasonic (acoustic) method. The process is then repeated except that this time sound is transmitted radially outward from acoustic transducer **122** and is received by transducer **120** by reversing their transmitting and receiving functions.

The technique of using a reflected acoustic signal is documented in Section 7.5 Reflected-path Systems of ISO 6416:2004(E). Note that in Section 7.5.4 of this standard it is stated that "The configuration of a reflector system is not that of the symmetrical crossed paths, and it is possible for the direction of flow to change within the gauging section. The reflector system therefore will not give reliable correction for skew flow". This embodiment uses small beam angles such as the preferred 11.25 degrees to result in a small gauging section—meaning that the influence of skew flow referred to in the above statement is minimized in this invention. An aspect of the invention is the use of small beam angles to significantly reduce the likelihood of a flow direction change within the gauging section.

FIG. **4** shows sixteen (16) measurement planes, each labelled as **13***a* to **13***p* respectively. Any number of planes may be used, sixteen planes are illustrated for the sake of description of the function of providing multiple measurement planes. The average velocity is measured in each of these measurement planes. Any number of measurement planes may be adopted as limited by the geometric constraint of fitting the acoustic transducers around the periphery of cylindrical member **114**. The smaller the size of the acoustic transducers the greater the number of measurement planes that may be employed. The velocity in the radial planes located between these measured planes can be interpolated from the values measured within each of the measurement planes as shown in FIG. **5**. The velocity measured in each plane is plotted against the angle of that plane. The velocities in each plane are shown as points V**13***a* to V**13***p* plotted against the angle of the plane **13***a* to **13***p*. If a line **142** is constructed joining each of these velocity-angle measurements then any velocity at angle **144** can computed given knowledge of the equation describing this line. The area beneath the line joining the angle-velocity points **146** can then be computed as shown in FIG. **6** to determine the total velocity passing through the pipe **102** and hence the total volumetric flow rate passing through the pipe **102**.

If an infinite number of measurement planes were defined around the angular span of pipe **102**, then the total flow rate passing through the pipe **102** could be computed by simply performing an angular integration of the average velocities passing through each measurement plane. In the embodiment shown in FIG. **7**, an infinite number of measurement planes could be inspected by rotating a single acoustic plane **148** through a continuous revolution using an electric motor **150** or any other mechanism for achieving angular rotation and an angular position sensor such as an encoder **152**. The transducers measure the average velocity within each radial plane and this measurement is recorded against the angle. The velocity measurement is made at every angle within the 360 degree angular range of the pipe **102**, and an angular integration is performed to compute the entire velocity field passing through the pipe **102**. However, the use of motor **150** requires a sealed rotating shaft and consumes power and adds cost.

FIG. **8** illustrates the attachment of smooth longitudinal member **114** to a bracket **154** installed through an access port **156** on the side of pipe **102**. Propeller meters of the prior art also use this type of access to the inside of pipe **102** and again the invention can be a drop-in replacement for propeller meters. Bracket **154** is of a streamlined profile to minimize drag and head loss and to minimize the potential for debris objects to snag thereon. A cap member **158** is connected to the free end of bracket **154** and can be sealed to the outer periphery of pipe **102**. The operation of the flow meter is identical to that of FIG. **1** and is also centrally located within pipe **102**.

The embodiments of FIGS. **1** and **8** may include a plurality of flow straightening vanes **160** attached to smooth longitudinal member **114** upstream of acoustic transducers **120**, **122**. The inclusion of these straightening vanes is illustrated in FIGS. **9** and **10**. Vanes **160** will reduce flow swirl and further increase the repeatability and measurement accuracy of the invention

The construction of the acoustic array **118** is shown in FIGS. **11** to **13**. FIG. **11** shows a donut shaped body member **162** to receive the acoustic transducers **120**, **122**. Acoustic transducers **120**, **122** are set at the desired angle through appropriate recesses **164** in body member **162**. FIG. **13** shows the construction of the acoustic array **118** by having a sandwich formed by a pair of donut shaped body members **162** separated by a spacer **166**. The length of spacer **166** dictates the relative position of reflection on the internal wall of pipe **102**, and so governs the location that the reflection is received back at the acoustic array **118**. The spacer **166** is used to ensure that the reflection arrives at the centre of the face of the receiving transducer **122**.

FIG. **14** is a variation of FIG. **13** where the space between the body members **162** can be adjusted to suit requirements. In this embodiment spacer **166** may be implemented as part of an adjustable mechanism using the relative motion of a nut incorporated into the upstream body member **162** travelling along a threaded stem **168**. The adjustment is indicated by arrows **170**. Linear sealing techniques could be employed to maintain a waterproof environment for this vertical translation mechanism, for example, a sealed telescoping shaft as commonly employed in linear actuators. The spacing between the two body members **162** could be adjusted by rotating the threaded stem by hand or this process could be automated using an electric motor and such that the transducer spacing is correctly configured for the pipe diameter that the flow measurement device is inserted into. Other alternatives of linear translation may be used to set the spacing between the two body members **162**.

A greater number of measurement planes can also be achieved by combining multiple acoustic arrays **118**, each having an angular offset required to achieve greater angular resolution **172**, as illustrated in FIG. **15**. In FIG. **15** the multiple acoustic arrays are configured as two pairs, one pair upstream of the other. An alternative approach would be to inter-leave two pairs of acoustic arrays such that the acoustic arrays are combined in the sequence PairA**1**-PairB**1**-PairA**2**-PairB**2**. This alternative configuration is illustrated in FIG. **15**A.

FIG. **16** shows a method of formation of the acoustic array **118**. The acoustic array **118** is constructed from a plurality of acoustic transducers **120**, typically piezo transducers which are soldered to electrical connections on printed circuit boards **174** and **176** by conducting cables **178**, **180**. Each of the printed circuit boards **174**, **176** are connected by a board-to-board connector **182** which connects all electrical terminals of the piezo transducers **120** to the one circuit board **176**. An external signal loom **184** having an electrical connector **186** is then connected to circuit board **176**, and the entire assembly is then encapsulated by potting or other common encapsulation technique to render it water proof This encapsulation forms the donut-shaped body member **162** shown in FIGS. **11** and **17**. It would be understood by a person skilled in the art that the piezo transducers **120** would have an acoustically damping material such as cork or rubber bonded to their back face to muffle the acoustic signal on the internally oriented face such that the sound is focused solely on the outer face of the piezo transducers **120**. In addition an acoustic window is provided to seal the outer face of the piezo transducer **120**.

Rather than setting the acoustic arrays **118** to suit the internal diameter of pipe **102** by adjusting the gap between acoustic arrays **118** as shown in FIG. **14**, the length of the smooth cylindrical longitudinal member **114** could remain constant and the acoustic transducers **120**, **122** could be adapted to be in a tiltable design to be rotated about their centre as indicated by arrows **188** to configure the beam angle required for the acoustic beam to be received in the centre of the receiver transducer **122**.

The use of a relatively small angle of 11.25 degrees of the acoustic transducers as discussed with reference to FIGS. **3** and **4** will provide more tolerance for the acoustic arrays **118** to off centre alignment or an out-of-round pipe **102**. Referring to FIG. **19**, in the event that the member **114** is not centred, or is firing at an out-of-round pipe **102**, the reflected signal is received by the receiving transducer **122** off centre relative to the face of the transducer **122**. The translation of the received beam **126***a* off centre, indicated by measurement D in FIG. **20**, is smaller the smaller the angle of the acoustic array **118**. The degree of shift off centre of the received transducer is related to the degree of eccentricity or out-of-roundness by the trigonometric tangent relationship. The smaller the beam angles the smaller the influence of eccentricity or out-of-roundness.

The centrality of the installation can be assessed by the combination of travel time measured within each plane, and by the signal strength of the echo received in each plane. If the member **114** is perfectly concentric within a perfectly round pipe **102**, then for a homogeneous fluid with a homogeneous temperature, the sum of the travel times in the upstream and downstream direction would be identical in each plane of measurement. If, in one plane of measurement, the acoustic transducers **122** lie further away **102***a* from the internal perimeter of the pipe **102** than in the opposite plane, then the sum of the travel times in the upstream and downstream directions would be greater in the plane furthest from the pipe wall. A comparison of the travel times in each plane can be used to assist in the centring of the acoustic array **118**.

Alternatively, a third acoustic array **190** may be provided in each plane and mounted parallel to the pipe wall, so that the signal emitted from transducers **192** intersect the pipe wall orthogonally and are then reflected back to the same transducer **192** which receives the echo. This arrangement is illustrated in FIGS. **21** and **22**. The distance between the transducers **192** and the pipe wall is thereby measured by flight time of this acoustic pulse. If these additional transducers **192** are provided in at least three planes **194**, **196**, **198** separated by 120 degrees, then the concentricity of the longitudinal member can be verified. This centricity information can be provided on a user interface display (not shown) to assist the technician to achieve a concentric installation. The invention may also include a self-centering system in which a feedback control mechanism is used to adjust the position of the acoustic arrays. Such an orthogonal acoustic array may also be mounted on a travelling arrangement such as a cable mechanism and drawn through the length of a pipe **102** or of a well such as an oil or gas exploration well to provide a high resolution image of the pipe walls without the use of a rotating assembly as is currently known to be employed.

The amplitude of the received signal can also be used as an indication of internal fouling of the pipe walls, and a software algorithm could be used to determine the depth of fouling on the pipe walls.

If the longitudinal member **114** of FIG. **8** is installed through the access port **156** of pipe **102**, then adjustability **200** can be built into the mounting bracket **154** to allow the position of the longitudinal member **114** to be adjusted relative to the centre of pipe **102**, as shown in FIG. **23**.

The longitudinal member **114** may also be installed eccentrically within the pipe **102** as illustrated in FIG. **24**. As can be seen in this configuration the acoustic planes **124**, **126** have differing lengths along the outside perimeter of the acoustic arrays depending on their closeness to the respective inner wall of pipe **102**. Alternatively, the transducers in each acoustic plane could be oriented at the angle required for the respective path length to the internal wall of the pipe as illustrated in the variations of pipes **102** shown in FIG. **25**. FIG. **25** shows examples of non-circular or polygonal pipes **102** which are not circular in cross-section. The invention, in principle, can use any shape with a matching shape of longitudinal member **104**.

FIGS. **26** to **31** show the location of the flow meter **100** in relation to a pump **202**.

FIG. **26** shows a screw pump **202** powered by motor **206** through output shaft **204**. Flow meter **100** is positioned on the discharge side of screw pump **202**.

FIG. **27** shows flow meter **100** positioned on the suction side of screw pump **202**. FIG. **29** shows a variation of FIG. **27** specifically designed to prevent problems associated with cavitation on the suction side of pump **202**. The use of a flow meter **100** on the suction side of a pump **202** is generally prohibited by existing metering technologies because the low pressure on the suction side can lead to cavitation which prevents accurate flow measurement. This problem is avoided by locating the acoustic arrays **118** in a larger diameter inlet **208** on the suction side. Because the cross-sectional area of the inlet **208** is larger than the cross sectional area of the pump impeller pipe **102**, the fluid velocity is lower within the inlet than it is within the impeller pipe. This lower velocity prevents pressure drop and cavitation within the metering pipe **102**.

FIGS. **28** and **30** show a configuration in which the longitudinal member **114** is supported from the pump impeller **210**. The acoustic arrays may rotate with the impeller **210**, or may be designed to not rotate. These embodiments will create a pump with an integrated precision flow measurement capability.

FIG. **31** shows a filter cage **212** fitted to the base **214** of the pump inlet to prevent objects from entering the assembly and causing damage.

As seen in FIGS. **26** to **31** the acoustic arrays may be installed on the suction or discharge side of the pump **202** to provide an integrated flow measurement capability. The flow meter may be used with any type of pump either on the suction or on the discharge side.

This invention may be used to measure velocity of fluids or gases passing through a pipe or conduit of any shape. The cylindrical array described may be of any shape such that the acoustic transducer orientation is parallel to the internal wall of said pipe or conduit at each radial plane measured. This invention may have application in measurement of flow velocity and hence volumetric transfer in any fluid—including liquids, slurry, gas, air, powders or plasmas.

If a temperature sensor is installed in the flow meter, then the amount of heat being transferred through the pipe can also be calculated. Knowledge of the internal diameter of the pipe allows an accurate speed of sound measurement within the fluid which allows the temperature of the fluid to be determined from a look-up table or algorithm encoded into the sensor software. Additional sensors such as pressure sensors or chemical dosage sensors can also be inserted into the flow meter for further characterization of the fluid flowing through the pipe.

This invention describes an acoustic flow meter specifically designed for use in a pipe configuration in which a propeller meter has previously been used. The acoustic flow meter has no moving parts and does not get clogged by debris, and so presents significant maintenance cost advantages over propeller meters. The invention also provides redundancy and accuracy.

The preferred embodiments describe the use of the invention in pipes but it can also function in open channels as would be evident to a man skilled in the art.

The invention will be understood to embrace many further modifications as will be readily apparent to persons skilled in the art and which will be deemed to reside within the broad scope and ambit of the invention, there having been set forth herein only the broad nature of the invention and certain specific embodiments by way of example.

The invention claimed is:

1. A flow meter for a pipe or open channel, said flow meter including a longitudinal member adapted to, in use, be inserted into said pipe or open channel but free of any internal wall of said pipe or open channel, said longitudinal member having a plurality of pairs of acoustic transducers located therearound with each pair of acoustic transducers having a transmitting transducer and a receiving transducer, whereby said transmitting transducer sends an acoustic signal to an internal wall of said pipe or open channel and said receiving transducer receives the reflected acoustic signal.

2. The flow meter of claim **1**, wherein said longitudinal member has a cylindrical or polygonal shape.

3. The flow meter of claim **1**, wherein said longitudinal member is secured to an end cap member of a pipe riser.

4. The flow meter of claim, wherein said longitudinal member is mounted to a bracket installed through an access port on a side of said pipe.

5. The flow meter of claim **1**, wherein small angles separate respective pairs of acoustic transducers to significantly reduce a likelihood of a flow direction change within a measuring area for each pair of acoustic transducers.

6. The flow meter of claim **1**, wherein said longitudinal member is mounted on a shaft of an axial screw pump within said pipe.

7. The flow meter of claim **1** arranged in a large diameter pipe on a suction side of a pump, wherein said large diameter pipe, in use, prevents cavitation which prevents accurate flow measurement.

8. The flow meter of claim **1**, further including a plurality of flow straightening vanes attached to said longitudinal member upstream of said acoustic transducers.

9. The flow meter of claim **1** where one or both ends of the longitudinal member are capped with an aerodynamic profile to minimise turbulence and drag and to minimise a likelihood of debris fouling the flow meter.

10. The flow meter of claim **1** where an aerodynamic nose is located several diameters upstream of an acoustic transducer array to allow flow streamlines to align parallel to the pipe walls before crossing the acoustic transducer array.

11. The flow meter of claim **1**, wherein said acoustic transducers are switchable between receiving and transmitting acoustic signals.

12. The flow meter of claim **1**, wherein each of said receiving transducers is axially offset from each of said transmitting transducers.

13. The flow meter of claim **12**, wherein the axial offset between the receiving and transmitting transducers is adjustable so as to suit a multitude of different pipe internal diameters.

14. The flow meter of claim **1**, wherein at least one pair of acoustic transducers are arranged about said longitudinal member.

15. The flow meter of claim **1**, wherein said longitudinal member is centrally aligned with said pipe or open channel.

16. The flow meter of claim **1**, wherein said longitudinal member is eccentrically aligned with said pipe or open channel.

17. The flow meter of claim **1**, wherein each of said acoustic transducers can be adjusted for correct alignment.

18. The flow meter of claim **1**, wherein said longitudinal member is rotatable, in use.

19. The flow meter of claim **1**, wherein said acoustic transducers are set at a desired angle through appropriate recesses in a body member.

20. The flow meter of claim **1**, further including an acoustic array on said longitudinal member to allow for a concentricity of the longitudinal member to be verified.

21. The flow meter of claim **1**, further including use of multiple acoustic transducer arrays to increase an angular resolution of velocity samples.

22. The flow meter of claim **1**, wherein a relatively small angle of 11.25 degrees or less of the acoustic transducers is used to provide more tolerance for acoustic arrays to off centre alignment or an out-of-round pipe.

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